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Applicants   : Yutaka TAKAKUBO

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Appln. No. : Not yet assigned

Filed   : Concurrently herewith

For   : SCANNING OPTICAL SYSTEM

COVER LETTER REGARDING EXECUTED APPLICATION

Commissioner for Patents
Alexandria, VA 22313-1450

Sir:

The undersigned points out that the executed application being filed herewith includes pages 1 - 3 of the executed declaration which were forwarded to the undersigned by facsimile by Applicant's Japanese representative on September 9, 2003, and pages 1 - 34 of the specification (with Figures 1 - 10) which were forwarded to the undersigned by Applicant's Japanese representative on September 8, 2003. Further, the undersigned has been advised by the Japanese representative that the inventor had reviewed the application before executing the declaration.

Accordingly, Applicant respectfully submits that the present application is properly executed and should be considered as filed in executed form. However, if the U.S. Patent and Trademark Office determines that the present application is not properly executed,

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Applicant respectfully requests that the present application be treated as an unexecuted

application under 37 C.F.R. 1.53(f).

Should there be any questions regarding this paper, please contact the undersigned at

the below listed number.

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SPECIFICATION

Title of the Invention

[0001]   Scanning Optical System

Background of the Invention

[0002]   The present invention relates to a scanning optical system to be installed in printing devices such as color printers and color copy machines.

[0003]   As is widely known, a scanning optical system dynamically deflects a laser beam (which has been on-off modulated according to image information) by use of a rotational polygon mirror and converges the dynamically deflected laser beam on a surface of a photosensitive drum (scan target surface) by use of an imaging optical system, by which the spot beam is scanned on the scan target surface at a constant speed in a main scanning direction and thereby an electrostatic latent image composed of a plurality of dots is formed on the scan target surface.

[0004]   In conventional scanning optical systems installed in color printing devices, each photosensitive drum for each color component (e.g. yellow, magenta, cyan, black) was generally provided with one rotational polygon mirror and one imaging

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optical system for its own (see US patent USP6452687, for example).

However, there have recently been developed scanning optical

systems in which a rotational polygon mirror and part of an imaging

optical system are shared among the color components in order

to reduce manufacturing costs of printing devices (see US patent

USP6313906, for example).

[0005]   In such a scanning optical system, each of N laser

beams (N: the number of color components) before reaching the

rotational polygon mirror may be "tilted" in a plane that is

parallel to the central axis of the polygon mirror so that the

beams will travel along the plane and then intersect at a point

in the vicinity of a reflecting surface of the polygon mirror.

Such a technique has been elaborated on in the specification

and figures of US Patent Application No. 10/294615 previously

filed by the assignee of the present invention. In this case,

after being reflected by the rotational polygon mirror, the N

laser beams pass through a common front lens group of the imaging

optical system gradually separating from one another as shown

in Fig. 9 (cross-sectional view of the scanning optical system),

pass through N rear lens groups of the imaging optical system

respectively, and are then incident on N photosensitive drums

parallelly arranged at preset intervals respectively.

[0006]   Incidentally, while the photosensitive drums shown

in Fig. 9 overlap with one another, enough space is kept between

any two adjacent photosensitive drums in actual scanning optical

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systems so that necessary parts (development module, toner cartridge, etc.) can be placed in the space.   Therefore, in such a scanning optical system, any two adjacent laser beams to be incident on the photosensitive drums have to be separated from each other to match the distance (interval) between adjacent photosensitive drums.

[0007]   In order to realize the separation of the laser beams, the scanning optical system has to be designed employing one of the following three configurations: a first configuration in which the optical path length between the polygon mirror and each photosensitive drum is set long; a second configuration in which the angle between adjacent laser beams incident on the polygon mirror is set large; and a third configuration in which the optical path of each laser beam after passing through the front lens group is bent by one or more mirrors and thereby the separation between adjacent laser beams is increased as shown in Fig. 10.

[0008]   However, the first configuration has the disadvantage of increasing the size of the printing device. Meanwhile, in the second configuration, it is difficult to correct scan line curves and twist of wavefront aberration (twist of the wavefront) at the same time, by which attaining enough scanning performance becomes difficult.   Consequently, the third configuration like the one shown in Fig. 10 is generally employed for the above-described scanning optical system.

[0009]   However, in the third configuration like Fig. 10 in

which mirrors are placed on the optical paths of the laser beams,

the cost for manufacturing the system rises as the number of

optical elements increases. Further, if the precision of each

mirror surface is not maintained high, scanning performance of

the system tends to vary among the color components and thereby

misregistration or misalignment in color superposition

(hereafter called "color misregistration") occurs when a

plurality of images of the color components are overlaid.

Summary of the Invention

[0010]   The present invention is advantageous in that it

provides a scanning optical system capable of sufficiently

separating the laser beams to match the intervals between the

photosensitive drums without the need of long optical paths,

without deteriorating the scanning performance, and without the

need of using mirrors causing the color misregistration and

increasing the cost.

[0011]   In accordance with an aspect of the present invention,

there is provided a scanning optical system for dynamically

deflecting a plurality of laser beams by a deflecting system

for a plurality of scan targets which are provided corresponding

to the laser beams and parallelly arranged at preset intervals,

converging the dynamically deflected laser b ams by an imaging

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optical system into spot beams on the corresponding scan targets

respectively, and thereby scanning the spot beams in a main

scanning direction on the corresponding scan targets

respectively. In the scanning optical system, the deflecting

system includes at least one reflecting surface which

simultaneously deflects the laser beams that are incident on

the reflecting surface at incident angles differing in an

auxiliary scanning direction perpendicular to the main scanning

direction. The imaging optical system includes: a front lens

group having positive refractive power for converging all the

laser beams from the deflecting system principally in the main

scanning direction while deflecting at least a pair of laser

beams selected from the laser beams obliquely incident on the

reflecting surface so as to let the selected laser beams deviate

from an optical surface reference axis of the front lens group;

and a plurality of rear lens groups each of which has positive

refractive power for converging each of the laser beams that

passed through the front lens group principally in the auxiliary

scanning direction.

[0012]   With such configuration of the scanning optical system,

even when the optical path length is relatively short, scan line

curves can be satisfactorily corrected while fulfilling basic

specs of scanning performance required of scanning optical

systems, and furthermore, the twist of the wavefront can be

reduced to a sufficiently low level. Therefore, the laser beams

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can be separated sufficiently to match the intervals between the scan targets without the need of using mirrors which cause the color misregistration and increasing the cost, by which variations in the scanning performance causing the color misregistration can be prevented.

[0013]   Optionally, at least one surface of the front lens group may have a plurality of areas of different shapes for interacting with the laser beams respectively.

[0014]   Still optionally, the at least one surface of the front lens group may be formed as a step-like optical surface in which lens thickness changes at each boundary between adjacent areas.

[0015]   Still optionally, each area of the at least one surface of the front lens group may be formed as a two-dimensional polynomial aspherical surface which is expressed by a polynomial expression regarding heights in the main scanning direction and the auxiliary scanning direction.

[0016]   In a particular case, the two-dimensional polynomial aspherical surface of the front lens group may be asymmetric in the main scanning direction.

[0017]   Additionally or alternatively, the two-dimensional polynomial aspherical surface of the front lens group may be asymmetric in the auxiliary scanning direction.

[0018]   Optionally, surfaces on at least one side of the rear lens groups may be formed so as not to be in the same shape.

[0019]   Still optionally, at least one surface of each of the

rear lens groups may be formed as a two-dimensional polynomial aspherical surface which is expressed by a polynomial expression regarding heights in the main scanning direction and the auxiliary scanning direction.

[0020]   In a particular case, the two-dimensional polynomial aspherical surface of each of the rear lens groups may be symmetric with respect to the optical surface reference axis in the main scanning direction.

[0021]   Additionally or alternatively, the two-dimensional polynomial aspherical surface of each of the rear lens groups may be asymmetric in the auxiliary scanning direction.

[0022]   Optionally, the pair of laser beams obliquely incident on the deflecting system travel at the same tilt angle on both sides of a main scanning plane which is defined as an imaginary plane parallel to the main scanning direction and including the optical surface reference axis of the front lens group. In this case, rear lens groups for transmitting the pair of laser beams respectively are formed in shapes mirror-symmetrical with each other with respect to the main scanning plane as a symmetry plane.

[0023]   Still optionally, the pair of laser beams obliquely incident on the deflecting system travel at the same tilt angle on both sides of a main scanning plane which is defined as an imaginary plane parallel to the main scanning direction and including the optical surface reference axis of the front lens group. In this case, areas of the front lens group for interacting

with the pair of laser beams respectively are formed in shapes mirror-symmetrical with each other with respect to the main scanning plane as a symmetry plane.

[0024]   Still optionally, the pair of beams are deviated from the optical surface reference axis of the front lens group by the front lens group in the auxiliary scanning direction.

[0025]   According to another aspect of the invention, there is provided a scanning optical system for dynamically deflecting a plurality of laser beams by a deflecting system for a plurality of scan targets which are provided corresponding to the laser beams and parallelly arranged at preset intervals, converging the dynamically deflected laser beams by an imaging optical system into spot beams on said corresponding scan targets respectively, and thereby scanning the spot beams in a main scanning direction on said corresponding scan targets respectively.   In the scanning optical system, the deflecting system includes at least one reflecting surface which simultaneously deflects the laser beams that are incident on the at least one reflecting surface at incident angles differing in an auxiliary scanning direction perpendicular to the main scanning direction. The imaging optical system includes: a front lens group having positive refractive power for converging all the laser beams from said deflecting system principally in the main scanning direction while deflecting at least a pair of laser beams selected from the laser beams so that the pair of laser

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beams are deviated from an optical surface reference axis of said front lens group in the auxiliary scanning direction; and a plurality of rear lens groups each of which has positive refractive power for converging each of the laser beams that passed through said front lens group principally in the auxiliary scanning direction.

[0026]   With such configuration of the scanning optical system, even when the optical path length is relatively short, scan line curves can be satisfactorily corrected while fulfilling basic specs of scanning performance required of scanning optical systems, and furthermore, the twist of the wavefront can be reduced to a sufficiently low level. Therefore, the laser beams can be separated sufficiently to match the intervals between the scan targets without the need of using mirrors which cause the color misregistration and increasing the cost, by which variations in the scanning performance causing the color misregistration can be prevented.

Brief Description of the Accompanying Drawings

[0027]   The objects and features of the present invention will become more apparent from the consideration of the following detailed description taken in conjunction with the accompanying drawings, in which:

[0028].   Fig. 1 is a perspective view schematically showing

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the optical composition of a scanning optical system in accordance with an embodiment of the present invention;

[0029]　　Fig. 2 is an optical block diagram of the scanning optical system seen in the main scanning direction;

[0030]　　Fig. 3 is an optical block diagram of an inner optical system of the scanning optical system seen in the main scanning direction;

[0031]　　Fig. 4 is an optical block diagram of an outer optical system of the scanning optical system seen in the main scanning direction;

[0032]　　Fig. 5 is an optical block diagram of the scanning optical system seen in the auxiliary scanning direction;

[0033]　　Figs. 6A through 6D are graphs showing fθ characteristics, curvature of field, a scan line curve and wavefront aberration of the inner optical system;

[0034]　　Figs. 7A through 7D are graphs showing fθ characteristics, curvature of field, a scan line curve and wavefront aberration of the outer optical system;

[0035]　　Fig. 8 is a graph showing wavefront aberration of a laser beam scanned by the scanning optical system of the embodiment;

[0036]　　Fig. 9 is a schematic diagram showing optical paths of laser beams in a conventional scanning optical system; and

[0037]　　Fig. 10 is a perspective view schematically showing the optical composition of a conventional scanning optical

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system.

Detailed Description of the Embodiments

[0038]   Referring now to the drawings, a description will be given in detail of a preferred embodiment in accordance with the present invention.

[0039]   The scanning optical system explained below will be assumed to be installed in a color laser printer that prints a color image at high speed by successively transferring four toner images of four color components (yellow, magenta, cyan and black) to paper during one paper feed cycle.

[0040]   Fig. 1 is a perspective view schematically showing the optical configuration of a scanning optical system in accordance with an embodiment of the present invention. Fig. 2 is an optical block diagram of the principal part of the scanning optical system seen in the main scanning direction. The scanning optical system of this embodiment is a system having four photosensitive drums that are scanned with four separate laser beams respectively. As shown in Fig. 1, the scanning optical system includes a photosensitive drum Y for yellow, a photosensitive drum M for magenta, a photosensitive drum C for cyan and a photosensitive drum K for black which are arranged in parallel at preset intervals in the aforementioned order.

[0041]   In the laser printer including the scanning optical

system, the photosensitive drums Y, M, C, K are arranged along the paper feed direction (top-to-bottom direction in Fig. 1). Incidentally, the surfaces of the four photosensitive drums Y, M, C, K are drawn simply in Fig. 2 as one scan target surface S. As shown in Figs. 1 and 2, the scanning optical system includes a light source unit 1, a cylindrical lens 2, a polygon mirror 3 and an imaging optical system 4.

<Light Source Unit>

[0042]   First, the light source unit 1 will be explained in detail. The light source unit 1 includes a laser diode chip in which four laser diodes corresponding to the four color components are integrated into one body, a collimator lens for collimating the laser beams (emitted from the laser diodes as diverging beams) into parallel beams, etc. From the light source unit 1, four laser beams corresponding to the four color components are outputted being parallelly arranged in a plane at even intervals. The direction in which the four laser beams are arranged is parallel to the paper feed direction.

<Cylindrical Lens>

[0043]   Next, the cylindrical lens 2 will be explained. The cylindrical lens 2 has a cylindrical surface on the beam incident side and a plane surface on the beam emerging side. The cylindrical lens 2 converges the four laser beams emitted by the light source unit 1 on a point only in the auxiliary scanning direction.

<Polygon Mirror>

[0044]   Next, the polygon mirror 3 will be explained in detail.
The polygon mirror 3 is formed in the shape of a low-profile
regular octagonal prism having eight lateral faces as reflecting
surfaces. The polygon mirror 3, having a central axis 3a parallel
to the paper feed direction, is placed at a proper position so
that one of its lateral faces (reflecting surfaces) will be put
in the vicinity of the point where the four laser beams from
the cylindrical lens 2 converge.

[0045]   Being driven and revolved around the central axis 3a
at a constant angular velocity, the polygon mirror 3 functions
as a deflecting system for dynamically deflecting the laser beams.
The four laser beams that passed through the cylindrical lens
2 are simultaneously reflected by one reflecting surface of the
polygon mirror 3 toward the imaging optical system 4. According
to the rotation of the polygon mirror 3, the four laser beams
are dynamically deflected in the main scanning direction.

[0046]   If we define a "main scanning plane" as an imaginary
plane including the converging point (where the four laser beams
converge) and orthogonal to the central axis 3a of the polygon
mirror 3, the main scanning plane is situated in between the
inner two photosensitive drums M and C. Out of the four laser
beams incident on the polygon mirror 3, inner two beams travel
symmetrically on both sides of the main scanning plane, and outer
two beams also travel symmetrically on both sides of the main
scanning plane. Thus, the inner two laser beams have opposite

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tilt angles relative to the main scanning plane (the same absolute value of tilt angle), and the outer two laser beams similarly have opposite tilt angles relative to the main scanning plane (the same absolute value of tilt angle).

<Imaging Optical System>

[0047]   Next, the imaging optical system 4 will be explained in detail. The imaging optical system 4 is a group of lenses having the function of correcting the scanning speed, which includes a front lens group 4a (on the side facing the polygon mirror 3) and rear lens groups 4y, 4m, 4c and 4k (on the side facing the photosensitive drums Y, M, C and K). Incidentally, at least one optical surface of each lens group (4a, 4y, 4m, 4c, 4k) is formed as a rotationally asymmetrical surface ("two-dimensional polynomial aspherical surface") as will be explained later, and such a rotationally asymmetrical optical surface does not have an axis like the symmetry axis of a rotationally symmetrical optical surface. Therefore, a term "optical surface reference axis" is defined here as an axis passing through the "origin" that is set when the shape of the optical surface is described in a mathematical expression, and the "optical surface reference axis" will hereafter be regarded as one that corresponds to the symmetry axis of a rotationally symmetrical optical surface (i.e. the optical axis).

[0048]   The front lens group 4a has pow r for deflecting the laser beams (which have been dynamically deflected by the polygon

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mirror 3) to deviate from the optical surface reference axis both in the main scanning direction and in the auxiliary scanning direction while converging the laser beams principally in the main scanning direction. The front lens group 4a is placed to have its optical surface reference axis Ax situated on the main scanning plane. The front surface 4a-a of the front lens group 4a is formed as a continuous surface having rotational symmetry, with its symmetry axis coinciding with the optical surface reference axis Ax.

[0049]   Meanwhile, the rear surface of the front lens group 4a is formed to have four areas 4a-y, 4a-m, 4a-c and 4a-k of different shapes specifically designed to transmit the four laser beams respectively adding separate effects to them. Concretely, the rear surface is formed as a step-like optical surface having the discrete areas 4a-y, 4a-m, 4a-c and 4a-k of different heights arranged in the paper feed direction (the direction of the central axis 3a of the polygon mirror 3). Incidentally, the optical surface reference axis of the shape of each area (4a-y, 4a-m, 4a-c, 4a-k) of the rear surface coincides with the optical surface reference axis Ax of the front lens group 4a.

[0050]   Since the inner two laser beams travel symmetrically on both sides of the main scanning plane in this embodiment, the inner two areas 4a-m and 4a-c of the rear surface interacting with the inner two laser beams are formed as two mirror-symmetrical surfaces with respect to the main scanning

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plane as the symmetry plane. Similarly, the outer two areas
4a-y and 4a-k of the rear surface interacting with the outer
two laser beams are formed as two mirror-symmetrical surfaces
with respect to the main scanning plane as the symmetry plane.
Therefore, the whole front lens group 4a is formed in a shape
having mirror symmetry with respect to the main scanning plane.

[0051]   Each rear lens group (4y, 4m, 4c, 4k) has power for
converging a corresponding laser beam (which has been dynamically
deflected by the polygon mirror 3 and which passed through the
front lens group 4a) principally in the auxiliary scanning
direction, while having the function of compensating for
curvature of field in the auxiliary scanning direction. Out
of the rear lens groups 4y, 4m, 4c and 4k, inner two rear lens
groups 4m and 4c for the inner two laser beams traveling nearby
the main scanning plane (hereafter, also referred to as "inner
optical systems") are formed in shapes that are
mirror-symmetrical with each other and are placed at positions
and in directions that are mirror-symmetrical with each other
with respect to the main scanning plane (symmetry plane).

[0052]   Similarly, outer two rear lens groups 4y and 4k for
the outer two laser beams traveling apart from the main scanning
plane (hereafter, also referred to as "outer optical systems")
are formed in shapes mirror-symmetrical with each other and are
placed at positions and in directions mirror-symmetrical with
each other with respect to the main scanning plane (symmetry

plane).

[0053]   The four laser beams dynamically deflected by the
polygon mirror 3 successively pass through the front lens group
4a and the rear lens groups 4y, 4m, 4c and 4k, by which the laser
beams are converged into spot beams on separate photosensitive
drums Y, M, C and K, respectively. Each spot beam scans the
surface of a corresponding photosensitive drum (Y, M, C or K)
in the main scanning direction (shown with a straight arrow in
Fig. 1) at a constant speed. Each laser beam to repetitively
scan the surface of each photosensitive drum (Y, M, C, K) has
been on-off modulated according to image information. Thus,
on the surface of each photosensitive drum rotated at a constant
angular velocity, two-dimensional electrostatic latent image
composed of a plurality of dots is formed.

<Numerical Configuration of Scanning Optical System>

[0054]   In the following, concrete numerical configuration
of the scanning optical system of this embodiment will be
explained in detail. The following Tables 1 and 2 show concrete
numerical configuration of the inner optical system and the outer
optical system of the scanning optical system of this embodiment,
respectively. Fig. 3 is an optical block diagram of the inner
optical system seen in the main scanning direction, and Fig.
4 is an optical block diagram of the outer optical system seen
in the main scanning direction.

[0055]   In Fig. 3, in addition to the inner area 4a-m (4a-c)

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of the rear surface of the front lens group 4a for transmitting
the inner laser beam, the whole shape of an imaginary lens
including the inner area 4a-m (4a-c) is shown, without showing
the shape of the outer area 4a-y (4a-k) for transmitting the
outer laser beam.   In contrast, in Fig. 4, the whole shape of
an imaginary lens including the outer area 4a-y (4a-k) for
transmitting the outer laser beam is shown, without showing the
shape of the inner area 4a-m (4a-c) for transmitting the inner
laser beam.

[0056]   TABLE 1

Surface	Ry	Rz	d	N	DECZ
#1	∞	-51.080	4.000	1.51072	0.00
#2	∞	∞	97.000	--	--
#3	∞	∞	62.610	--	0.00
#4	-185.410	-185.410	10.000	1.48617	0.00
#5	-67.00	-100.000	132.470	--	--
#6	-427.700	-427.700	5.000	1.48617	15.50
#7	-695.750	-695.720	79.730	--	--
#8	∞	∞	--	--	-0.65

[0057]   TABLE 2

Surface	Ry	Rz	d	N	DECZ
#1	∞	-51.080	4.000	1.51072	0.00
#2	∞	∞	97.000	--	--
#3	∞	∞	62.610	--	0.00
#4	-185.410	-185.410	10.000	1.48617	0.00
#5	-67.00	-100.000	132.470	--	--
#6	-400.900	-400.900	8.000	1.48617	42.00
#7	-695.720	-695.720	79.730	--	--

#8   ∞   ∞   --   --   3.62

[0058]   In Tables 1 and 2, the character "No" indicates surface
numbers that are assigned to optical surfaces of the scanning
optical system starting from the front surface of the cylindrical
lens 2 (on the beam incident side), in which No.1 and No.2 denote
the front and rear surfaces of the cylindrical lens 2, No.3 denotes
a reflecting surface of the polygon mirror 3. No.4 denotes the
front surface of the front lens group 4a, No.5 in Table 1 denotes
the inner area 4a-m (4a-c) of the rear surface of the front lens
group 4a, No.5 in Table 2 denotes the outer area 4a-y (4a-k)
of the rear surface of the front lens group 4a, No.6 and No.7
in Table 1 denote the front and rear surfaces of the inner rear
lens group 4m (4c), No.6 and No.7 in Table 2 denote the front
and rear surfaces of the outer rear lens group 4y (4k), and No.8
denotes the scan target surface S.

[0059]   The character "Ry" denotes the curvature radius [mm]
of each optical surface on its optical surface reference axis
measured in the main scanning direction, and "Rz" denotes the
curvature radius [mm] of each optical surface on its optical
surface reference axis measured in the auxiliary scanning
direction.   The character "d" denotes the distance [mm] between
the optical surface and the next optical surface measured on
the optical surface reference axis, and "N" denotes the
refractive index of each lens at a d sign wavelength 780 nm.

[0060]   The character "DECZ" generally denotes a shift amount
[mm] of the optical surface reference axis of each optical surface
relative to the optical surface reference axis of the anterior
surface measured in the auxiliary scanning direction.
Concretely, for each rear lens group (4y, 4m, 4c, 4k), "DECZ"
means the shift amount [mm] of its optical surface reference
axis Ax' (see Figs. 3 and 4) relative to the optical surface
reference axis Ax measured in the auxiliary scanning direction.
For the scan target surface S (No.8), "DECZ" means the shift
amount [mm] of the laser beam incident point on the scan target
surface S relative to the optical surface reference axis Ax'
measured in the auxiliary scanning direction.   The focal length
of the whole system is 220 mm and the effective scan width on
the scan target surface S is 216 mm.

[0061]   If we define an "auxiliary scanning plane" as an
imaginary plane including the optical surface reference axis
Ax and perpendicular to the main scanning plane, when the optical
path of each laser beam incident on the polygon mirror 3 is
projected on the auxiliary scanning plane, the incident angle
of the inner laser beam on the reflecting surface of the polygon
mirror 3 of this embodiment is 1.9 ° as shown in Fig. 3, and
the incident angle of the outer laser beam on the reflecting
surface of the polygon mirror 3 is 5.2 ° as shown in Fig. 4.
Meanwhile, when the optical path of each laser beam incident
on the polygon mirror 3 is projected on the main scanning plane,

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each incident laser beam is tilted relative to the optical surface reference axis Ax by 74.0 ° as shown in Fig. 5.

[0062]   In this embodiment, the front surface 4a-a of the front lens group 4a (4th optical surface) is formed as a concave spherical surface, and the rear surface (4a-y, 4a-m, 4a-c, 4a-k) of the front lens group 4a (5th optical surface) is formed as a two-dimensional polynomial aspherical surface. The front surfaces of the inner and outer rear lens groups 4y, 4m, 4c and 4k (6th optical surfaces) are also formed as two-dimensional polynomial aspherical surfaces. The rear surfaces of the rear lens groups 4y, 4m, 4c and 4k (7th optical surfaces) are formed as convex spherical surfaces.

[0063]   The "two-dimensional polynomial aspherical surface" means a curved optical surface whose SAG amount from an imaginary reference plane is defined by a polynomial expression $X(y,z)$ including variables y and z as two-dimensional coordinates on the reference plane in the main scanning direction (y direction) and the auxiliary scanning direction (z direction). In the two-dimensional coordinates, the origin is defined as the intersecting point of the reference plane and a single reference axis that is perpendicular to the reference plane. Concretely, the shape of the two-dimensional polynomial aspherical surface is expressed as explained below.

[0064]   The two-dimensional polynomial aspherical surface is expressed by the following SAG amount $X(y,z)$ from the reference

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plane, measured at each point (y,z) on the reference plane:

$$X(y,z) = C(y^2 + z^2)/\left\{1 + \sqrt{1 - (1+\kappa)C^2(y^2 + z^2)}\right\} + \sum \sum B(m,n)y^m z^n \qquad \cdots (1)$$

where "C" denotes the curvature (1/Ry: the inverse of the curvature radius Ry shown in Table 1) on the optical surface reference axis measured in the main scanning direction, "κ" denotes a conical coefficient, and "B(m,n)" with non-negative integers m and n denotes an aspherical surface coefficient of m-th and n-th orders in the main and auxiliary scanning directions respectively.

[0065]   The following Table 3 (for the inner optical system) and Table 4 (for the outer optical system) show concrete examples of the aspherical surface coefficients B(m,n) when the 5th optical surface (rear surface of the front lens group 4a) is described by the expression (1). Aspherical surface coefficients B(m,n) having values 0 are omitted in Tables 3 and 4. The conical coefficient κ in the expression (1) of the 5th optical surface is 0.000 for both the inner and outer optical systems.

[0066]   TABLE 3

B_{mn}	n=0	n=1	n=2	n=3	n=4
m=0	0.0000	1.4790E-01	3.4730E-03	-1.8260E-04	1.7420E-06
m=1	-1.7460E-05	7.9330E-06	2.5380E-06	-9.5680E-07	1.5070E-07
m=2	6.2720E-05	3.9620E-06	2.2500E-06	-6.3370E-08	-1.2000E-08

m=3	2.3890E-07	-1.4120E-07	6.0670E-08	-7.7220E-09	-2.3150E-10
m=4	1.5000E-07	1.2840E-09	-1.0030E-09	1.1830E-10	-6.3320E-12
m=5	-1.0560E-10	0.0000	-1.3710E-13	6.6090E-13	-1.6460E-13
m=6	1.6890E-11	1.0650E-12	-6.8390E-13	1.1720E-13	2.2870E-15
m=8	6.1110E-15				

[0067]   TABLE 4

B_{mn}	n=0	n=1	n=2	n=3	n=4
m=0	0.0000	4.0310E-01	1.6570E-04	4.4290E-06	-2.0080E-07
m=1	-1.5690E-04	-7.7550E-05	3.5050E-05	-3.9660E-06	1.3770E-07
m=2	4.1050E-04	5.0450E-07	4.0540E-06	-1.2460E-08	-1.1210E-08
m=3	3.1650E-06	-1.2840E-06	1.7010E-07	-6.0230E-09	-1.3660E-10
m=4	1.6290E-07	1.6550E-08	-2.2010E-09	1.1180E-10	-6.4090E-12
m=5	-1.4820E-10	0.0000	-1.2140E-12	1.4610E-12	-1.5490E-13
m=6	1.7710E-11	5.2480E-12	-1.4120E-12	9.3990E-14	1.8890E-15
m=8	7.8250E-15				

[0068]   In Tables 3 and 4, aspherical surface coefficients B(m,n) with "m" of odd orders (m = 1, 3, 5, · · ·) are nonzero, therefore, the rear surface (4a-y, 4a-m, 4a-c, 4a-k) of the front lens group 4a (5th optical surface) is asymmetric in the main scanning direction with respect to the optical surface reference axis.   Further, since aspherical surface coefficients B(m,n) with "n" of odd orders (n = 1, 3, 5, · · ·) are also nonzero, the rear surface (4a-y, 4a-m, 4a-c, 4a-k) is asymmetric also in the auxiliary scanning direction with respect to the optical surface reference axis.

[0069]   The following Table 5 (for the inner optical system) and Table 6 (for the outer optical system) show concrete examples

of the aspherical surface coefficients B(m,n) when the 6th

optical surface (front surface of a rear lens group) is described

by the expression (1). Aspherical surface coefficients B(m,n)

having values 0 are omitted in Tables 5 and 6. The conical

coefficient κ in the expression (1) of the 6th optical surface

is 0.000 for both the inner and outer optical systems.

[0070]   TABLE 5

B_{mn}	n=0	n=1	n=2	n=3	n=4
m=0	0.0000	2.1860E-01	1.7000E-02	-1.1650E-05	-2.5240E-06
m=2	2.3280E-05	-1.4020E-06	-2.4480E-07	-1.5820E-08	-6.6080E-10
m=4	8.0310E-08	-3.3670E-10	1.3800E-11	-2.9060E-13	-3.3280E-14
m=6	-1.2360E-12	1.5350E-14	-1.2270E-15	2.2660E-16	-2.5240E-14
m=8	-1.6530E-17				

[0071]   TABLE 6

B_{mn}	n=0	n=1	n=2	n=3	n=4
m=0	0.0000	4.2370E-01	1.4510E-02	7.9270E-06	-2.3440E-06
m=2	1.5410E-04	-1.9500E-07	-2.0920E-07	-1.3280E-08	-6.5640E-10
m=4	7.0530E-08	-8.3290E-10	3.8090E-11	1.6690E-13	-3.2900E-14
m=6	-6.2170E-13	3.0600E-14	-3.0700E-15	2.4940E-16	-2.5070E-18
m=8	3.4540E-17				

[0072]   In Tables 5 and 6, aspherical surface coefficients

B(m,n) with "m" of odd orders (m = 1, 3, 5, · · ·) are all zero,

therefore, the front surface of each rear lens group (4y, 4m,

4c, 4k) (6th optical surface) has a shape that changes

symmetrically in the main scanning direction with respect to

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its origin.

[0073]   Figs. 6A through 6D and Figs. 7A through 7D are graphs

showing optical performance figures of the inner optical system

and the outer optical system of the scanning optical system

respectively, in which Figs. 6A and 7A show fθ errors (deviation

of the spot beam on the scan target surface S from the ideal

position measured in the main scanning direction), Figs. 6B and

7B show curvatures of field (deviation of the image focusing

position from the ideal plane measured in the optical axis

direction) in the main scanning direction (broken line) and in

the auxiliary scanning direction (solid line), Figs. 6C and 7C

show scan line curves (Bow), and Figs. 6D and 7D show wavefront

aberrations.   In each graph, the vertical axis (y) denotes the

scan position in the main scanning direction [mm], and the

horizontal axis (x) denotes the amount of aberration.   The unit

of aberration on the horizontal axis is [mm] in Figs. 6A - 6C

and Figs. 7A - 7C and [λ] (wavelength) in Figs. 6D and 7D.

[0074]   Fig. 8 is a wavefront aberration diagram of the

scanning optical system of this embodiment, in which the two

endpoints of the vertical axis (representing the amount of

aberration) are apart from the origin by $\pm 0.2\lambda$.

[0075]   As shown in Figs. 6A through 8, the scanning optical

system of this embodiment satisfactorily corrects the Bow (the

scan line curve) while fulfilling basic specs of scanning

performance (fθ error, curvature of field) required of scanning

optical systems. Further, the twist of the wavefront is reduced to a sufficiently low level.

[0076]   Further, according to the scanning optical system of the above embodiment, the optical path length between the polygon mirror 3 and the photosensitive drums Y, M, C and K can be shortened, by which the need of using mirrors in the imaging optical system 4 (causing the color misregistration and increasing the manufacturing cost) is eliminated.

[0077]   Therefore, the laser beams can be separated sufficiently to match the intervals between the photosensitive drums without the need of long optical paths, without deteriorating the scanning performance, and without the need of using mirrors causing the color misregistration and increasing the cost.

[0078]   While the present invention has been described with reference to the particular illustrative embodiments, it is not to be restricted by those embodiments but only by the appended claims. For example, while a polygon mirror was employed as the deflecting system for dynamically deflecting the laser beams in the above embodiment, other types of deflecting systems such as a galvanometer mirror can also be employed in the scanning optical system and the present invention is also applicable to such scanning optical systems. It is to be appreciated that those skilled in the art can change or modify the embodiments without departing from the scope and spirit of the present

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invention.

[0079]   The present disclosure relates to the subject matter contained in Japanese Patent Application No. P2002-265668, filed on September 11, 2002, which is expressly incorporated herein by reference in its entirety.